Experimental Test for Size Effects in Impact Fragmentation. K. R. Housen and M. E. Voss
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Predictions of how collisional fragmentation events depend on size scale have varied dramatically over the past decade. Initially, it was assumed that a small-scale experiment could be used to model a much larger scale collision as long as the kinetic energy per unit target mass was the same in both events. More recently, scaling analyses (1, 2) and hydrocode calculations (3) suggest that large targets, up to about 1 km in size, are significantly weaker than the much smaller objects used in laboratory impact experiments. As such, the energy per unit mass required to fragment a 10 cm target could be much larger than that required to fragment a kilometer-sized body.

Weakening with increased size has been explained in terms of growth and coalescence of *in situ* flaws. Consider a sequence of collisional experiments in which all initial conditions remain constant, except that the impactor and target are continually enlarged in the same proportion. With increasing size, the duration of the stress pulses inside the target increase, providing additional time for activated cracks to grow and coalesce. Additionally, larger targets should include correspondingly larger, and therefore weaker, flaws which reduce target strength.

Depending on the physical mechanisms invoked, scaling theory and hydrocode analyses have indicated that the kinetic energy per unit target mass, Q^*, required to reduce a target to one-half it's original mass, should vary as a power of the target radius, R, with the power law exponent ranging anywhere from 0 to -0.6. When scaling over several orders of magnitude in target size, the range of this exponent produces considerable uncertainty in the specific energy needed to disrupt an asteroid-sized object.

To date, the question of size dependence has not been addressed experimentally, primarily because of practical difficulties. In particular, size effects cannot be uncovered by simply varying the target size; the impactor size must also be varied as much as possible. An unambiguous test for size effects is best obtained from collisions in which all parameters are constant except for the size scale of the experiment. This abstract summarizes a preliminary series of such tests. The initial results demonstrate, for the first time, a decrease in target strength with increasing event size.

Experiments were performed at two sizes to provide a factor of ten variation in scale (see Table 1). Because a precise match to a desired impact velocity could not be attained, tests were conducted over a range of impact velocities. This also provided information on how the mass of the largest fragment depends on Q, the energy per unit target mass.

Impacts were conducted on cylindrical targets, all of which were sawed from a common block of Georgia Keystone granite (density = 2.63 gm/cm^3). In the small tests, a 0.25"-bore powder gun was used to launch cylindrical aluminum projectiles. The targets were placed on a foam pedestal inside a plastic container in which a small hole was drilled so that the projectile could enter, but nearly all impact fragments would be retained. The inside of the container was lined with foam to prevent damage to the fragments. The targets were oriented such that a flat face of the impactor struck the center of a flat face of the target. The large scale tests used a 2.5"-bore light gas gun to launch the projectiles. To capture the fragments, the targets were placed in a foam-lined 55 gal. steel drum that included an entrance hole for the impactor. As in the small tests, the impactors were aluminum cylinders whose flat face struck the center of a flat face of the target.

Figure 1 shows the ratio of the mass of the largest fragment, M_L, to the original target mass, M. In the small scale tests, M_L/M decreases with increasing energy per unit target mass, with some scatter due primarily to the natural inhomogeneity involved in brittle fracture of rock. The fragmentation threshold, i.e., $M_L/M = 0.5$, occurs at a specific energy of $Q^* = 1.6 \times 10^7$ ergs/gm. However, a test with a large target at this same value of Q (and impact velocity) resulted in much more damage, and a value of M_L/M of only 0.06. Two additional tests with large targets showed that Q had to be reduced by about a factor of 3 in order to attain $M_L/M = 0.5$. Hence the targets in the larger scale events were significantly weaker than those in the smaller tests.

Scaling analysis (1, 2) predicts that M_L/M should be a function of Q $R^{9\mu/(2\phi-3)}$ $U^{3\mu-2}$, where U is the impact velocity, μ is the point-source coupling parameter exponent, typically about 0.55 for nonporous materials, and φ is the exponent in the relation $n \propto \sigma^{\phi}$ (σ = flaw activation stress, n = no. of flaws per unit volume activated at stress < σ). Using values of μ=0.55 and φ=9 (4) gives Q $R^{0.33}U^{-0.35}$. Figure 2 shows this scaling form correlates the results for the two target sizes quite well.

Using the limited data shown in Figure 2, the fragmentation threshold for granite targets is found from the condition $M_L/M = 0.5$: $Q^* = 4 \times 10^5\, R^{-0.33} U^{0.35}$ (cgs). Analysis of the fragment size distributions is underway, and additional experiments at intermediate target sizes are planned.

Refs. (1) Housen and Holsapple, *Icarus*, **84**, 226-253, 1990. (2) Holsapple, *Planet. Space Sci.*, **42**, 1067-1078, 1994. (3) Ryan, *LPSC XXIV*, 1227, 1993. (4) Melosh, Ryan and Asphaug, *Journ. Geophys. Res.*, **97**, 14735-14759, 1992.

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Table 1. Summary of experimental conditions and results

	Target				Impactor							
Test	M mass	D diam	H height	D/H diam/hgt	m mass	h height	d diam	d/h diam/hgt	U velocity	M/m targ/imp	Q K.E./mass	ML/M Larg. frag/targ
-	gm	cm	cm	-	gm	cm	cm	-	km/s	-	erg/gm	-
1430	66.8	3.25	3.07	1.06	0.54	0.66	0.62	0.93	0.58	124.5	1.33E+07	0.621
1431	66.7	3.24	3.05	1.06	0.54	0.64	0.63	0.98	0.58	122.7	1.35E+07	0.774
1432	66.9	3.25	3.07	1.06	0.55	0.65	0.61	0.95	0.41	121.5	6.75E+06	0.993
1434	66.7	3.23	3.07	1.05	0.46	0.53	0.62	1.16	0.77	144.8	2.02E+07	0.163
1435	66.7	3.25	3.07	1.06	0.44	0.53	0.62	1.17	0.70	152.4	1.61E+07	0.591
1436	66.9	3.25	3.07	1.06	0.43	0.53	0.62	1.18	0.71	155.0	1.63E+07	0.556
1437	66.8	3.25	3.07	1.06	0.44	0.53	0.63	1.19	0.55	152.2	9.76E+06	0.813
1438	75,977.5	34.42	31.24	1.10	499.20	5.75	6.34	1.10	0.68	152.2	1.50E+07	0.064
1439	76,540.0	34.42	31.24	1.10	499.00	5.75	6.34	1.10	0.57	153.4	1.06E+07	0.121
1440	75,908.8	34.42	31.24	1.10	498.30	5.74	6.34	1.10	0.42	152.3	5.79E+06	0.539